Estimation of Size and Shape of Citrus Fruits Using Image Processing for Automatic Grading

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Abstract— **Size is one of the important parameters in grading of fruits. Also quantifying the fruit's shape gives value addition to the fruits. This paper describes analytical methods to estimate the size and shape of citrus fruits to grade them based on single view fruit images. Sweet-lime and orange fruits are taken for case study of size and shape determination respectively. The size of the sweet-lime fruits were estimated and graded into three categories using simple methods like radius signature method, area method and perimeter method. Also the existing method based on Light Detection and Ranging (LIDAR) sensor for citrus fruits size determination was improved through a method employing image processing. The shapes of the orange fruits were estimated using Heuristic Shape separator method and shape numbers were obtained for varying shaped orange fruits. The results were found to be reasonably in good agreement with the human assessment.**

Keywords—grading; single view; size; shape; LIDAR; machine vision; image processing

I. Introduction

Many commercial factors like pricing, identification of a fruit by name, grading, sorting, etc., are decided not only by the shape but also by the size of a fruit [1]. Sorting of fruits based on size or shape is one of the important tasks performed in the packinghouses. Size or shape parameter influence grading of fruits and consumer acceptance in the market.

Size of a fruit is an important factor as consumers have an inclined preference for bigger and colourful fruits. There is a minimum diameter requirement for acceptance of fruits as marketable, and size inspection is a critical part of grading fruits. Size of a fruit is an indirect measurement of its volume and if the fruit density of a particular fruit variety is assumed to be constant, then the system can estimate fruit weight from the volume, replacing the need for a weighing device [2].

Post-harvest visual inspection and grading of produce by hand is a difficult, labor intensive, subjective task, unreliable, costly and highly inconsistent. Nowadays, Machine vision based systems are gaining popularity due to various advantages compared to conventional manual inspection. Image processing techniques have accomplished non-destructive analysis of fruits allowing easier determination of size and colour of fruits [3]. In literatures, various techniques were suggested for estimating the size of objects like Boundary encoding [4], curvature, compactness, bending energy & maximum-minimum diameters [5],[6]. Fast Fourier Transform analysis for size inspection of potatoes based on elongation ratio was derived from Fourier harmonics [7]. Size was estimated from area measurements in certain variety of fruits [8], from perimeter and diameter in certain other fruits. Measurement of size was also done based on the ratio of major and minor axes of fruits [9].

Yamakawa, Khot, Ehsani and Konda [10] have developed a fruit quality monitoring system consisting of a Light Detection and Ranging (LIDAR) sensor that was used to measure the diameter of the fruit. The sensor was set at an angle range to measure the maximum diameters of the fruit in such a way as to calculate the distance between the extreme left and extreme right (tangential) points. This lead to a value equal to a chord length that is considerably lesser than the actual diameter.

Various techniques were reported in literatures, for shape identification and grading. They may be categorized as 1) Boundary encoding technique [4] for finding shape number, 2) Statistical analysis using moments [8], bending energy, radius variation and fractures, 3) Structure analysis from geometry [11] and 4) Spectrum analysis [12]. Although many such general techniques were documented in computer vision literature, the natural variability and diversity of biological materials create difficult and practical problems [13]. In general, two approaches [14] namely, region based information and boundary information are adopted for shape extraction of fruits. The first approach is based on geometric parameters while the second approach involves computations of Fourier descriptors. In analyzing shape, image moments and various

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types of moment-based invariants were also used to describe quantitatively the shape of an object [15].

This paper describes simple analytical methods for estimation of size and shape of citrus fruits like orange, sweet-lime and lemon based on single view fruit images unlike multiple views, thereby reducing the processing time, without compromising the accuracy of classification. This study uses single camera unlike multiple cameras used by other researchers. The existing method based on Light Detection and Ranging (LIDAR) sensor for citrus fruits size determination was improved through a method employing image processing. Literature survey reveals that not much work has been carried out in estimation of size and shape of citrus fruits like oranges, sweet-limes and lemons.

II. MATERIALS AND METHODS

A. *Machine vision system used for imaging of the citrus fruits - Experimental Setup*

For our experiments, PULNIX 6700 progressive scan camera was used, with resolution of 768 x 494 pixels and capture rate of 60 frames per minute. The camera also has other features such as adjustable shutter speeds, remote control through RS 232C interface, etc. The image available in the frame buffer was addressed by the CPU at pixel level through software. A NI1428 frame grabber was used in our application. Enough care was taken in the proper design of diffused illumination system for capturing clear images of the fruits which would reduce the pre-processing and enhancing the image before final analysis is carried out.

The acquired scene, which was in RGB colour space, was first converted into HSI colour space. The background was totally removed by means of selective hue component elimination to retain the images of fruits in the scene. The image was converted into binary form by suitable thresholding and then the contour of each fruit was detected by applying suitable filter.

Before performing operations to estimate the size or shape of the fruit from its image, it is essential to calibrate the imaging setup. Fruits were imaged with known scale factor, i.e. pixels/mm using a standard graph sheet. This factor is taken as a standard for a particular setup. All these processes were done on the basis of underlying assumption that the illumination and imaging setup are fixed. Any alteration to the setup like adjusting the position of the camera may lead to a different calibration factor.

B. *Methods of Analysis*

The proposed analytical methods estimate the size and shape parameter of citrus fruits needed for classification, based on single view images of the fruits. Mathematical analysis were carried out using MATLAB (Version R2010a) Image Processing Toolbox software. The contour of the fruit image is obtained in terms of pixel co-ordinates. Therefore suitable transformations have to be used for implementing these algorithms in practical applications. The units of all measurements and results presented are in pixels.

1) *Methods based on Size:* Four methods were proposed to analyse the contours of the fruit images for size determination. For getting the contour, a test/sample image of a citrus fruit (Fig. 1) was taken and processed. From the processed binary image (Fig. 2), the contour plot of the fruit (Fig. 3) was obtained. The contour of the citrus fruit was approximated to a circle and its area and perimeter were computed.

Fig. 1. Sample Image

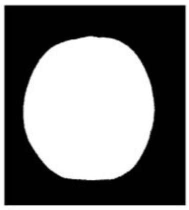


Fig. 2. Binary Image

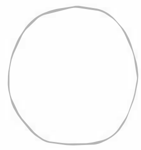


Fig. 3. Contour Image

a) Size determination based on Radius signature: As the diameter of the fruit is considered to be one of the important fruit quality parameters, by measuring the radius, the diameter can be found out. Initially, after getting the contour of the fruit image, the centroid (Xc, Yc) is determined using Green's Theorem based on area moment of inertia as below:

$$Xc = \Big[\iint_{x,y\,object} x\,dx\,dy\Big] / \Big[\iint_{x,y\,object} dx\,dy\Big] = \sum_{k=0}^{n}[y_k(x_k^2 - x_{k-1}^2) - x_k^2(y_k - y_{k-1})] \,/\, 2\sum_{k=0}^{n}[y_k(x_k - x_{k-1}) - x_k(y_k - y_{k-1})] \quad (1)$$

$$Yc = \Big[\iint_{x,y\,object} y\,dx\,dy\Big] / \Big[\iint_{x,y\,object} dx\,dy\Big] = \sum_{k=0}^{n}[y_k^2(x_k - x_{k-1}) - xk(y_k^2 - y^2_{k-1})] \,/\, 2\sum_{k=0}^{n}[y_k(x_k - x_{k-1}) - x_k(y_k - y_{k-1})] \quad (2)$$

After finding the centroid, pixel points at equiangular intervals, say 'N', normalized boundary points $\{(x_1, y_1), (x_2, y_2), (x_3, y_3)\ldots..\}$ are obtained [1]. The local radii corresponding to these points can then be determined as

$$r(k) = [(x_k - x_c)^2 + (y_k - y_c)^2]^{1/2}, \quad k = 1,2,\ldots\ldots\ldots N \quad (3)$$

The radius is then taken as the mean or the median of the local radii and the corresponding mean diameter and median diameter are calculated.

b) Size determination based on Area: The diameter can be calculated by measuring the area of the citrus fruit by approximating it to a circle. The area of the contour plot is obtained by calculating the number of white pixels on the binary image. The average diameter is then obtained using the formula,

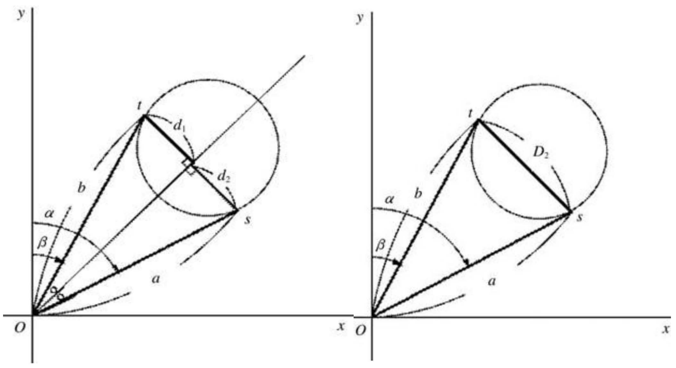
$$Area = [\pi * (diameter)\ \hat{}\ 2] / 4 \quad (4)$$

c) Size determination based on Perimeter: The diameter can also be calculated by finding the perimeter of the fruit contour, as given in the formula

$$Perimeter = \pi * diameter \quad (5)$$

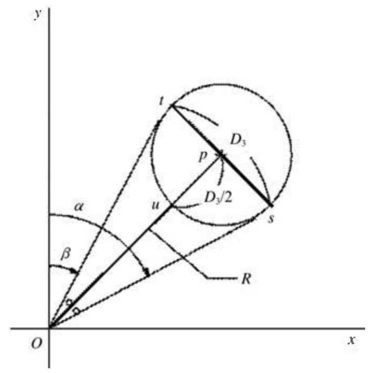
d) Size determination based on improved LIDAR sensor method: As an improvement of the method developed by Yamakawa, Khot, Ehsani and Konda [10] to determine the diameter of the fruits using LIDAR sensor, a similar method based on image processing technique was developed.

In the method developed by Yamakawa Khot, Ehsani and Konda [10], the LIDAR sensor was aligned at an angle range such that the maximum distance between two extreme ends of the fruit are covered. However, only the chord length was measured in such cases due to tangential view of fruits. This can be seen from Fig. 4a), Fig. 4b) and Fig. 4c) given by them. Critically evaluating, this way of measuring diameter may not give the correct result.



a) Perpendicular Approach

b) Law of cosines Approach



c) Bisector of angle Approach

Fig. 4. LIDAR sensor based fruit diameter measurement **Courtesy: [10]**

In Fig. 4, s – is the extreme right point of the fruit that the LIDAR sensor detected; *t* - extreme left point; *o* - point of the LIDAR sensor; *a* - the distance of the line *o-s*; *b* - distance of the line *o-t*; *α* is the angle from *y* axis to line *o-s*; and *β* is the angle from *y* axis to line *o-t* [10].

An image processing technique mimics the setup to provide the same chord length, and improves further by estimating the actual diameter. Thus the method is extended to obtain the actual diameter by measuring the chord length using image processing method, and then modifying the equations to get the actual diameter. Equations (6a), (6b), (6c) given by Yamakawa, Khot, Ehsani and Konda [10] and the proposed equations (7a), (7b), (7c) are as below:

$$D_1 = d_1 + d_2 = a \sin (\alpha-\beta)/2 + b \sin (\alpha-\beta)/2 \quad (6a)$$

$$D_2 = \sqrt{[a^2 + b^2 - 2ab \cos (\alpha-\beta)]} \quad (6b)$$

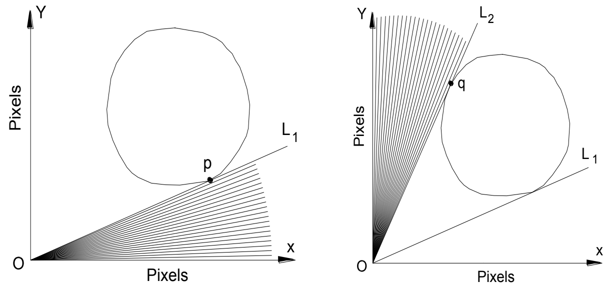
$$D_3 = [2R \tan (\alpha-\beta)/2] / [1 - (\alpha-\beta)/2] \quad (6c)$$

$$D_1 = d_1' + d_2' = a \tan (\alpha-\beta)/2 + b \tan (\alpha-\beta)/2 \quad (7a)$$

$$D_2 = \sqrt{[a^2 + b^2 - 2ab \cos (\alpha-\beta)]} / [\cos (\alpha-\beta)/2] \quad (7b)$$

$$D_3 = [2R \tan (\alpha-\beta)/2] / [1 - \tan (\alpha-\beta)/2] \quad (7c)$$

In the proposed method, the image is first padded to equal dimensions to obtain a symmetric contour plot. Then a line is plotted parallel to the X-axis starting from the end of the axis. The line is then tilted by small angles by changing the slope, until the line just touches the fruit image contour. This gives the first endpoint 'p' of the chord. Similarly, a second line is plotted parallel to the Y axis starting from the end and the slope is varied until it just touches the fruit image contour to obtain the second endpoint 'q' of the chord (Fig. 5). By joining the endpoints, the chord length 'pq' is obtained similar to the LIDAR sensor setup (Fig. 6). To obtain the actual diameter, line segments are drawn connecting the tangential endpoints p,q with the centroid, G. The length of these lines gives the radii d_1' and d_2' (Fig. 7). Based on (7a), (7b) and (7c), the actual diameter can be obtained using the same notations as in Fig. 4.



a. Left endpoint of the chord

b. Right endpoint of the chord

Fig. 5. Obtaining endpoints of the chord

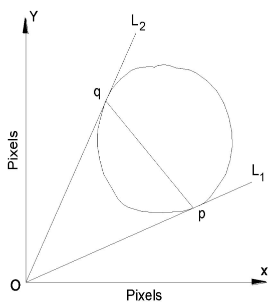


Fig. 6. Chord length of the fruit

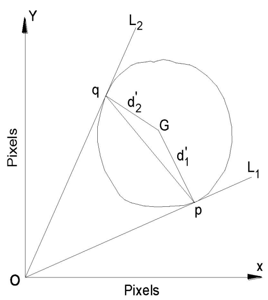


Fig. 7. Actual diameter of the fruit

As the sweet-lime fruit contours are assumed to be a circle, the diameter and hence the radius found by the above methods can be used to find the volume as given in (8)

$$V = 4 * \pi * r^3 / 3 \quad (8)$$

Knowing the average density of the fruit variety, fruit weight can also be estimated.

2) Method based on Shape: Treating the boundary signature as a one dimensional digital signal, it can be translated to Fourier domain [16] as

$$F(u) = (1/N) \sum_{k=1}^{N} r(k) \exp[-j2\pi uk/N],\ u = 0,1,2,...N/2 \quad (9)$$

where, $|F(u)|$ is the magnitude at harmonic frequency 'u' in the Fourier domain and 'k' is the number of boundary points. Here only the magnitude is taken into consideration.

These harmonics will then represent the shape information of the object. The boundary normalization and Fourier transformation will achieve significant information compression. The harmonic components in the Fourier domain represent the magnitude of boundary frequency changes in spatial domain $r(k)$ of the radius boundary sequence. Specifically, $F(0)$ will give the average radius after normalization, $F(1)$ will give the bending of an object, $F(2)$ will give the elongation of the object and so on [16].

For effective shape information extraction, a method of harmonics multiplied by its magnitude, $F(h)*h\hat{}m$ was established to provide an effective heuristic. It is determined as Shape separator, S [16] as given in (10). The higher the S, the more severity is the irregularity of the shape.

$$S = \sum F(h)*h\hat{}m, \quad h=0 \text{ to } 10 \ \&\ m=1,2 \text{ or } 3 \quad (10)$$

III. RESULTS AND DISCUSSIONS

A. Size estimation

About 60 sweet-lime fruits were separated roughly into three arbitrary grades, 20 fruits of each grade by a human expert grader, based on size. Ranges of sweet-lime fruit sizes were arbitrarily fixed as given in Table I.

TABLE I. SIZE RANGE OF DIFFERENT GRADES OF SWEET-LIME SAMPLES

Grade	Size in mm	Size in pixels
SLA	60 – 65	230 – 250
SLB	65 – 70	250 – 270
SLC	70 – 78	270 – 300

Out of the 60 fruits, ten fruits from each grade were taken as references for each grade and the remaining ten fruits of each grade were taken as samples for validation. One fruit of each reference grade is shown in Fig. 8 as example and were named as Grade SLA, Grade SLB & Grade SLC. The sample sweet-lime fruits were named as SL1, SL2,…SL30. After capturing the images of the above 60 fruits, using the MATLAB toolbox, the RGB values and the HSI values of all the fruits were determined and the size of the samples were computed using the above described methods. They were then graded based on the size range of that grade. The values of diameters obtained for few samples of sweet-lime fruits are given in Table II. The diameter values for the reference fruit images, SLA, SLB and SLC were computed to be 236 pixels, 255 pixels and 301 pixels respectively.

The diameters of fruits obtained through the above 4 methods were compared. The method based on LIDAR sensor employed through image processing gave results that were on par with the results obtained by using mean and median of local radii. The diameter obtained by calculating the area of the fruit was almost equal to the values obtained using the method based on LIDAR sensor employed through image processing. It is to be noted that the chord length calculated using the LIDAR technique was found to be much lesser than the actual diameter. For the sample fruits considered, the chord lengths found out as done in LIDAR sensor method was found to be only 90 – 95% of the value of the diameters calculated employing image processing. It was observed that results obtained using perimeter method was fairly inaccurate.

Grade SLA Grade SLB Grade SLC

Fig. 8. Grade references of Sweet-Lime fruits for Size analysis

The average values of the diameters obtained using the above methods were computed and the values of few samples are given in Table II. Based on these values, the grades were estimated and assigned using criteria given in Table I. It was found that except for sample SL5, all the other samples agreed with the manual assessment of grades, thus giving an accuracy of 94%. This may be due to the fact that the average diameter of the sample SL5 using the above methods lie on the border value between the size range of grade SLA and grade SLB.

The deviations between the actual diameters obtained using the four methods and the average diameter were calculated as shown in Table III. The average of the deviations in each method was computed. The method which gave the minimum of the average deviation was considered to be the best method. It was found that the radius signature method based on mean gave the least average deviation. For this method, the correlation coefficients between the samples and reference grades were calculated and are given in Table IV. The results show that the sample fruits agree with the reference fruits of the respective grade thus giving near 100% accuracy. Thus the radius signature method of grading is in good agreement with the visual inspection.

B. Shape estimation

The human experts also selected 60 orange fruits of good quality and graded them into three shape categories, 20 fruits of each category. As before, 10 fruits from each grade were taken as references for each grade and the remaining 10 fruits of each grade were taken as samples for validation. One fruit of each reference grade is shown in Fig. 9 as example and were named as Grade ORA, Grade ORB & Grade ORC. The sample fruits were named as OR1, OR2,…OR30.

TABLE II. VALUES OF DIAMETERS ESTIMATED USING DIFFERENT METHODS FOR SWEET LIME SAMPLES

Sample	Using Radius signature (Mean diameters)	Using Radius signature (Median diameters)	Using Area	Using Circumference	LIDAR - Actual Diameter	LIDAR - Chord Length	Av. diameter [Av. of columns *(1), (2), (3) & (5)*]	Estimated grade	Grade by manual assessment
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*
SL1	243.3755	243.8433	243.6228	263.1492	244.7295	232.8457	243.8928	**SLA**	**SLA**
SL2	244.5352	245.8744	244.7308	259.5027	246.2900	235.7873	245.3576	**SLA**	**SLA**
SL3	236.0523	235.7394	236.2789	251.1042	234.0750	223.6858	235.5364	**SLA**	**SLA**
SL4	243.0619	242.4640	243.3561	264.0496	244.3984	233.3448	243.3201	**SLA**	**SLA**
SL5	257.1413	257.0946	257.2259	275.6764	249.6319	234.5164	255.2734	**SLB**	**SLA**
SL6	252.7460	253.8217	252.9357	271.0976	254.2430	237.8968	253.4366	**SLB**	**SLB**
SL7	252.0073	252.7187	252.1138	268.5379	250.7368	237.4668	251.8942	**SLB**	**SLB**
SL8	259.2530	260.3009	259.3923	274.4219	262.3150	248.3445	260.3153	**SLB**	**SLB**
SL9	266.3927	266.5019	266.6415	284.9808	262.0521	251.4088	265.3971	**SLB**	**SLB**
SL10	264.9076	266.0162	265.0827	284.0165	264.3018	249.9136	265.0771	**SLB**	**SLB**
SL11	288.2112	288.0900	288.4499	307.0903	287.6721	276.2412	288.1058	**SLC**	**SLC**
SL12	298.1975	299.8809	298.1889	316.4670	281.7113	260.5635	294.4946	**SLC**	**SLC**
SL13	268.2871	271.4346	268.4286	285.6306	271.7735	252.5523	269.9810	**SLC**	**SLC**
SL14	274.5391	274.8076	274.7783	295.8298	274.3212	263.5963	274.6115	**SLC**	**SLC**
SL15	300.2315	300.6863	300.3166	319.4427	299.1771	276.9971	300.1029	**SLC**	**SLC**

TABLE III. DEVIATIONS BETWEEN THE ESTIMATED DIAMETERS AND AVERAGE ESTIMATED DIAMETERS OF SWEETLIME SAMPLES

Sample	Deviation b/w mean diameter based on radius signature and av. dia	Deviation b/w median diameter based on radius signature and av. dia	Deviation b/w diameter based on area and av. Dia	Deviation b/w diameter based on perimeter and av. dia	Deviation b/w diameter based on LIDAR technique and av. dia.
SL1	-0.51727	-0.049475	-0.269975	19.2564	0.836725
SL2	-0.8224	0.5168	-0.6268	14.1451	0.9324
SL3	0.5159	0.203	0.7425	15.5678	-1.4614
SL4	-0.2582	-0.8561	0.036	20.7295	1.0783
SL5	1.867875	1.821175	1.952475	20.403	-5.641525
SL6	-0.6906	0.3851	-0.5009	17.661	0.8064
SL7	0.11315	0.82455	0.21965	16.6437	-1.15735
SL8	-1.0623	-0.0144	-0.923	14.1066	1.9997
SL9	0.99565	1.10485	1.24445	19.5837	-3.34495
SL10	-0.16948	0.939125	0.005625	18.9394	-0.775275
SL11	0.1054	-0.0158	0.3441	18.9845	-0.4337
SL12	3.70285	5.38625	3.69425	21.9724	-12.78335
SL13	-1.69385	1.45365	-1.55235	15.6497	1.79255
SL14	-0.07245	0.19605	0.16675	21.2183	-0.29035
SL15	0.128625	0.583425	0.213725	19.3398	-0.925775
Av. of dev	**0.14286**	0.83188	0.31643	18.2801	-1.2911

TABLE IV. CORRELATION COEFFECIENTS OF SWEETLIME SAMPLES FOR RADIUS SIGNATURE METHOD

Sample	Correlation b/w Sample and Grade SLA	Correlation b/w Sample and Grade SLB	Correlation b/w Sample and Grade SLC
SL1	**0.5448**	0.4079	0.4121
SL2	**0.6311**	0.2038	0.3898
SL3	**0.6237**	0.0408	0.1764
SL4	**0.9247**	0.0759	0.5719
SL5	**0.9184**	0.3842	0.5893
SL6	0.4842	**0.6658**	0.0100
SL7	0.3542	**0.5736**	0.3470
SL8	0.0822	**0.5364**	0.2221
SL9	0.2718	**0.6747**	0.4412
SL10	0.1365	**0.4536**	0.1174
SL11	0.4198	0.1827	**0.5276**
SL12	0.0470	0.0660	**0.4374**
SL13	0.0670	0.3086	**0.5741**
SL14	0.4313	0.2751	**0.5627**
SL15	0.4557	0.2452	**0.6770**

Grade ORA Grade ORB Grade ORC

Fig. 9. Grade References of orange fruits for Shape analysis

After capturing the images of the above sample fruits using the MATLAB toolbox, the Fourier harmonics were calculated using (9) and corresponding Shape numbers were computed using (10) and these values for few fruits are tabulated under Table V. It was found that the first 10 harmonics maintain most of the information about the original shape.

From the Table V, it can be seen that sample oranges OR1 to OR5 belonging to Grade ORA have shape separator value ranging from 0.38 – 0.42, sample oranges OR6 to OR10 belonging to Grade ORB have shape separator value ranging from 0.34 – 0.38 and sample oranges OR11 to OR15 belonging to Grade ORC have shape separator value ranging from 0.30 – 0.34. Considering the dissimilarity order, it can be inferred that sample oranges OR1 to OR5 of Grade ORA are more dissimilar compared to sample oranges OR6 to OR10 of Grade ORB which in turn is dissimilar compared to sample oranges OR11 to OR15 of Grade ORC which was confirmed from their images.

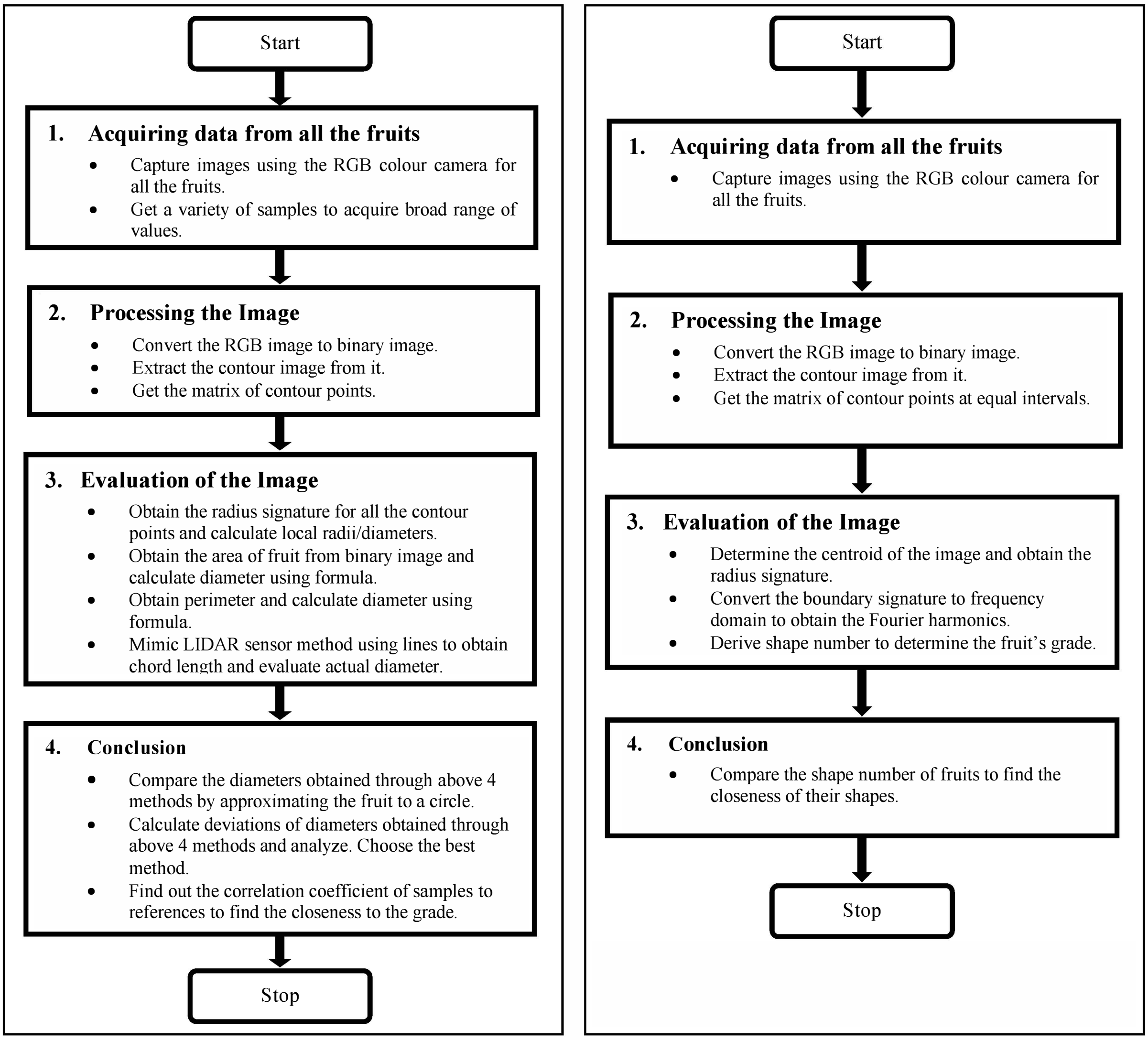
The algorithms used in the all the above proposed methods of size and shape estimation of citrus fruits is summarized and given in Fig.10.

IV. CONCLUSION

Different simple methods have been proposed for obtaining size and shape of citrus fruits like sweet-lime and orange. As a case study, the diameters of sweet-lime fruits were estimated and graded into three categories using four methods, namely, radius signature method, area method, perimeter method and method based on LIDAR sensor employed through image processing. It was found that of all the methods, the radius signature method based on mean was found to be the better method of size estimation and grading. Again as another case study, the shapes of the orange fruits were analyzed using Heuristic Shape separator method and shape numbers were obtained for varying shaped orange fruits. The results were found to be in good agreement with the human assessment. These methods can be extended to other fruit varieties also.

TABLE V. HARMONICS DATA AND SHAPE SEPARATOR VALUES FOR ORANGE FRUIT SAMPLES

	OR1	OR2	OR3	OR4	OR5	OR6	OR7	OR8	OR9	OR10	OR11	OR12	OR13	OR14	OR15
F0	137.557	143.955	136.188	139.853	148.325	139.932	117.430	119.538	113.428	112.806	110.372	111.624	119.632	119.890	118.918
F1	22.067	23.325	22.169	22.692	23.630	21.213	18.055	19.319	17.904	17.767	17.255	17.650	18.794	18.786	18.514
F2	11.078	11.775	11.256	11.434	11.808	10.269	8.820	9.692	8.892	8.788	8.487	8.757	9.308	9.308	9.142
F3	7.338	7.805	7.476	7.571	7.794	6.712	5.787	6.406	5.860	5.780	5.567	5.77	6.131	6.135	6.026
F4	5.452	5.798	5.558	5.622	5.778	4.959	4.282	4.752	4.343	4.278	4.116	4.278	4.543	4.546	4.470
F5	4.315	4.588	4.4	4.448	4.566	3.91	3.383	3.757	3.432	3.379	3.250	3.381	3.591	3.592	3.535
F6	3.555	3.779	3.625	3.664	3.758	3.221	2.781	3.093	2.826	2.787	2.674	2.784	2.956	2.957	2.91
F7	3.012	3.20	3.071	3.103	3.181	2.726	2.357	2.619	2.393	2.354	2.264	2.357	2.502	2.503	2.466
F8	2.603	2.767	2.656	2.683	2.748	2.356	2.037	2.264	2.0679	2.033	1.957	2.037	2.162	2.163	2.131
F9	2.286	2.429	2.332	2.355	2.412	2.068	1.788	1.987	1.816	1.785	1.719	1.788	1.898	1.898	1.871
F10	2.032	2.159	2.0738	2.094	2.144	1.838	1.589	1.766	1.614	1.586	1.528	1.590	1.687	1.687	1.663
$Sx10^3$	0.3927	0.415	0.3956	0.4028	0.419	0.3745	0.3694	0.342	0.3473	0.3539	0.3043	0.3125	0.3331	0.3334	0.329



a) Algorithm used in fruit size estimation b) Algorithm used in fruit shape estimation

Fig. 10. Algorithms used in the proposed methods of size and shape estimation of fruits

In majority of existing machine vision techniques, online size and shape of fruits are estimated using area and compactness/elongation-ratio of the fruit respectively where parameters like area, perimeter, major & minor axis length are only used. Here we have carried out the experiments/analysis using methods like radius signature and LIDAR based technique for size estimation, and Heuristic shape separator method for shape estimation, employing intense mathematical approach involving maximum number of boundary points for accurate determination of size and shape of the fruit which can take care of regular as well as irregular varieties of fruits giving more classification accuracy.

The proposed algorithms with suitable modifications can be implemented in real time mode depending upon the user requirements.

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